I Catt

27 May 1976/1

Electromagnetic Theory

First, a brief, hurried summary of the latest developments in the subject. Details will be filled in later.

Whereas usually the electric current is said to cause the fields within a (two wire) transmission line, Oliver Heaviside says "We reverse this"; the ~~fd~~ field (flux) travels down between the wires and causes an electric current in the wires.

We shall call the (normal theory), the conventional theory, that current flows down the wires and causes the E-M field the Normal theory, or Theory N. Heaviside's theory, that the field flows down between the wires and causes current in the wires we shall call Theory H.

The third, most recent theory is a step beyond Theory H and is called the Catt Theory, Theory C. In this theory, the field (flux) flows down between the wires and there is no electric current. Heaviside probably never got this far, although it will be ~~neces~~ necessary to research his latest writings to confirm this. It is noticeable that Gossick (and I think also ~~Josl~~ Josephs) says that Heaviside went senile, and ~~his later writing~~ Gossick says his later writings should be dismissed. Gossick has

D. BACKHOUSE, ST ALBANS.

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this

Heaviside went senile, and Gossick says his later writings should be dismissed. Gossick has dismissed the concept of Energy Current (the essence of Theory H) and so can safely be classified as holding to Theory N.

To a Theory N man, the assertion that there was no electric current would lead to the conclusion that the speaker/or writer was senile.

In general, what follows will be aspects of Theory C.

1. There is * no electric current.
2. A capacitor is a transmission line.
3. An inductor is a transmission line.
4. A transformer is a transmission line.

The velocity of an energy current in a perfect conductor is zero. That is, energy cannot enter a perfect conductor. [$c = \frac{1}{\sqrt{\mu\epsilon}}$, and ϵ for a perfect conductor is ∞]

Capacitor

All capacitors behave ~~as~~ as transmission lines in the ~~same~~ manner described for parallel voltage planes in my paper, IEEE Tran on Electronic Computers, Dec 1967, page 744. Because ϵ is very high, the outwards velocity of propagation is very slow.

ESR is the initial characteristic impedance of the transmission line.

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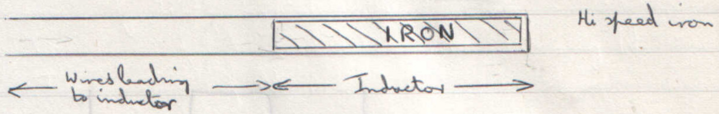
Inductor

Single turn inductor, iron cored.



$Z_0 \approx 100\Omega$

$© = ©_0$

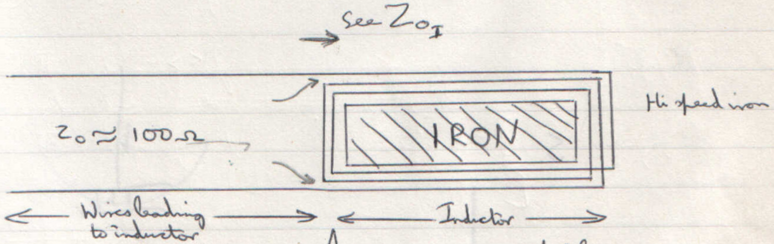
μ very high $\quad Z_{0_I} \approx \sqrt{\frac{\mu}{\epsilon}}$

$\therefore Z_0$ very high.

$© = \frac{1}{\sqrt{\mu\epsilon}}$ = ~~ver~~ very slow

since μ is so high.

Multi-Turn Inductor



μ very high.

"Z_{0_I}" is even larger than in ~~many~~ single turn inductor ~~be~~ as a result of crosstalk to other turns.

© still very slow.

At this point, use the approach in my paper in IEEE 1967 referred to below to calculate wavefronts launched to the right.

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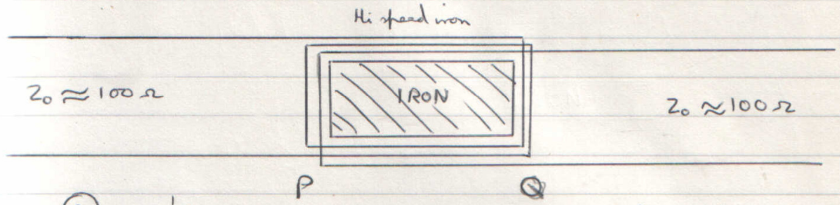
Transformer



$© = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

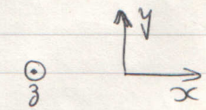
$Z_{0_{T_{IN}}}$ very high

$Z_{0_{T_{OUT}}}$ very high

© very slow.

$© = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

At P (and also at Q) reflections and crosstalk ~~o~~ occur between primary & secondary & also between windings of the primary. Again, follow the method for X talk between pairs of long lines described in my IEEE Dec 1967 paper. If Xformer core is air not iron, resistive ~~tape~~ paper analogy will work. { For resistive paper, take a cross section ⊥ to the paper and ⊥ to direction of transmission lines (i.e. in y z plane.)



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Real iron is not hi speed iron, so the full μ does not arise as the step, or wave front, passes the material. So with real iron the story is more complex, with new wave fronts being projected from behind the original wave front as the effective μ changes (as the magnetic material domains accelerate, gain velocity &c &c.)
Probably the best model to start with is an air cored Xformer or choke, get familiar with it & proceed from there to the more complex practical case of a slow (1 μsec) μ, that is a μ with finite (see 27 July 76) frequency bandwidth.

Discussion of Xformer on last page

An initial wave front ⌐ reaches P where it sees a ~~x~~ change of impedance from Z_0 so that there is a reflection ~~of~~ but some of the energy current continues towards Q. If μ is $> \mu_0$ the velocity between P & Q is slower. At Q, reflections occur and also some of the wave front proceeds further to the right on the secondary (o/p) of the transformer.

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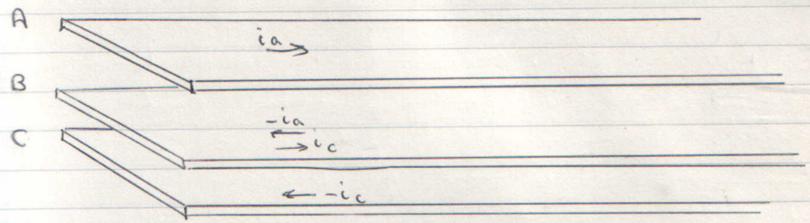
Transmission lines can be cascaded.



Assume no fringing (i.e. imagine a coax within a coax )

Keep μ, ϵ the same for line AB & line BC.

Project a step (wave front) down AB & at the same time project one down BC. It can be arranged that the first front ~~has~~ has currents $i_A = -i_B$ equal to those for the second wave front $i_B = -i_C$
Total current down B is then zero.
Plate B can be removed & wave fronts are unaffected. This is if stress level (in each energy current is the same! (E x H) Poynting vector

∴ wave fronts can be ~~cast~~ cascaded laterally.

∴ the Xmission line wave front rules apply to one ~~seg~~ segment (tube) of energy current just as much as the apply to the full

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energy current. So we can apply ideas of energy current to a small volume.

In a space with μ & ϵ, velocity of energy current is $Ⓒ = \frac{1}{\sqrt{\mu\epsilon}}$ (see my IEEE Dec 1967 paper).

<u>Discussion of ϵ.</u> High ϵ means "less voltage drop across for a given displacement current", in the language of Theory N (page 1).

A conductor allows "displacement current" or even "electric current" thru itself with no voltage drop. That is what is meant by "a conductor". $\therefore$ a conductor is a material with $\epsilon = \infty$.

$\therefore$ velocity of an energy current in a conductor is $Ⓒ = \frac{1}{\sqrt{\mu\epsilon}} = \frac{1}{\sqrt{\mu\infty}} = 0$.

So an energy current flows thru a conductor at zero velocity.

$\therefore$ an energy current cannot enter a ~~so~~ perfect conductor.

$\therefore$ in a two ~~wire~~ wire transmission line, the energy current is steered by the wires because ~~the~~ the energy current ~~can~~ cannot enter it, in the same way as water is steered ~~along~~ down a pipe because it cannot enter the metal of the pipe.

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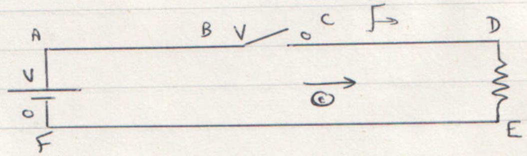
An energy current ~~enter~~ enters an imperfect conductor to the extent that the conductor will allow, or sustain, voltage drops thru itself (voltage drop in the Theory N sense) and so effect the equivalent of a ~~non surface~~ non-infinite ϵ.

An energy current limits the ~~ext~~ extent of its penetration of resistive transmission line wires in the same way as an overflowing river limits the ~~extent~~ speed to which it flows through the impeding bushes etc. far from its normal river bed.

<u>The Resistor.</u>



The energy stress, or pressure, ~~for~~ pushes throughout the rectangular space above and then expends itself through the open switch. The maximum stress (Theory N voltage drop) is across the switch contacts, and the energy stress then spreads out above the switch, the stress falling away with distance.

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to
When the switch is closed the pressure no longer exercises itself at that point, and rushes ~~to~~ to the right as the ~~(potential~~ potential ~~at C suddenly~~ (theory N) at C suddenly moves from 0v to V and a wave front rushes towards R at a velocity ⓒ. If R were zero Ω, the energy current would hit a solid wall of $\epsilon = \infty$ and bounce back.

However, an R allows the penetration of the energy current and its dissipation in a lateral mode.

In fact, a perfect conductor will not allow an energy current. $\epsilon_r = \infty$ so the current enters with zero velocity.

An R, however, does accept the incursion into its side of an energy current. Inside the R the energy current is converted into heat.

Electricity

"Electric current" is the edge of an energy current, nothing more, and so does not appear in Theory **C**. If the edge of an energy current is sharp, "electric current" would have to concentrate into zero width, rather absurd.

If transmission line conductors are imperfect so that the energy current penetrates, the "electric current" is spread down into

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the conductor. This ~~mean~~ merely means the edge of the energy current is not sharp. (a "skin depth" situation.)

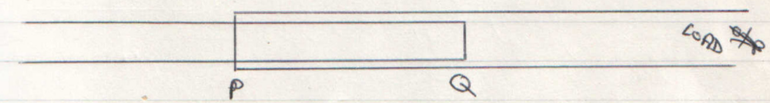
Units.

The ~~unit~~ unit of energy current is the Watt.

~~If~~ Energy current flows through a surface, so it has a current density. The unit of energy current density is the Watt per square metre. ~~This~~ This we shall provisionally call the "Heaviside". Mercer recently said that we ~~we~~ should ~~ha~~ have used the great man's name for one of our fundamental ~~units~~ units.

This name for Watts per square metre will need to be ratified by the international convention.

More thoughts on the transformer



We have a complex multiple reflection situation at P and at Q and at Load. Clearly, a low (say a short) at LOAD will send back reflections ~~calling for mor~~ finally calling for more I/P, only after alteration at Q & at P.

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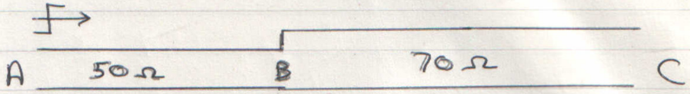
The story is ~~the~~ same if primary and/or secondary have more than one turn.

For years I have said that the change in impedance Z_0 of a transmission line is primarily a power transformer



A wave front 50v, 1a coming from ~~the~~ A

~~turns into~~ sees $\frac{Z-Z}{Z+Z} = \frac{70-50}{70+50}$

$= \frac{20}{120}$

$\frac{1}{6}$ th voltage increase at B,

a $\frac{50}{6}$ v wave front goes back to A.

Incident ~~energy~~ power was 50v x 1a = 50 watts.
Reflected power is $\frac{50}{6}$ v x $\frac{1}{6}$ a = $\frac{50}{36}$ watts.

∴ power which continues to the right is the remainder, i.e. $50 \times \frac{35}{36}$.

So only 3% of power is reflected.

If further downstream there is another ~~the~~

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change from 70Ω to 50Ω Z_0, a further 3% only of the power is reflected.

Generally, if Z_0 changes by $\frac{1}{x}$, power ~~refl~~ stopped (reflected) is $\frac{1}{x^2}$.

[If the above ~~calculat~~ calculation is wrong — it seems too good, or extreme, to be true — no matter. I've proved the key point in the past anyway, that very little power reflects at a "reasonable" discontinuity. The main effect is (say) v increases & i decreases, but power (v.i) hardly changes]

It follows that on entering the transformer at P (page 10) most ~~po~~ power continues. At Q, again most power continues. ~~only~~, Only, the v & i will obviously change, & it looks ~~at~~ as if it's by the turns ratio.

When we reach the load, the normal reflection – absorption rules apply, and if the load is "reasonable", ~~most~~ power will be absorbed. However, a short or

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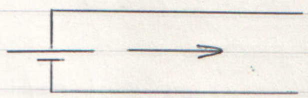
an open circuit will reflect 100% and rush back with its devastating news (power), hardly changing as it passes Q and P, to tell the source the doleful ~~tale~~ tale.

That is, in practice, the points P and Q do nothing to the passing power (energy current) but transform its v and i (in theory N). Of course, if the transmission lines Source → P and Q → load are identical the transformed power will not happily glide down from Q to load, and lots of reflections along that section will be needed. (That last sentence is partially valid only).

Battery, electrolysis, resistor.



Energy current is launched sideways from a battery and "walled in", or guided, by conductors.

Electrolysis

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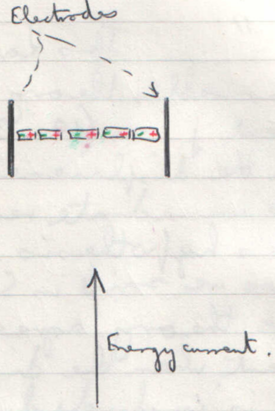
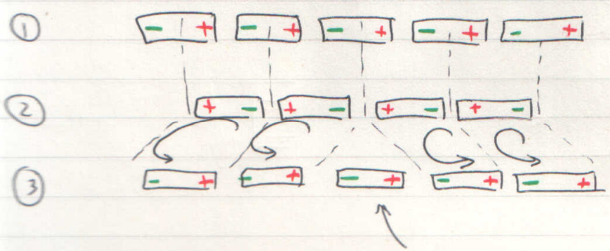
Energy current is absorbed and dissipated by various things including electrolysis or a resistor. A resistor is "non-directional electrolysis".

In electrolysis, we have no need of ions.



① A bridge of ~~~~ particles can reach from one electrode to the other. By chemical reaction, the electrode steals half of the nearest atom.

② The other half grabs the nearest half of the next one, and so on down the line.



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(3) The stress in the energy current (or field)

It turns them all round, and an extra one slips into the line.

(4) Start again.

This is a possible model, quickly conceived. The + & − are electric charge (theory N).

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Discussion of Energy Current.

Some time ago I typed out a document entitled "Electromagnetic Theory" which discussed many things, including Heaviside's ideas on the subject and including numerous quotations from his writings. It also included my 4 pp (approx) article "The Breakdown of Meaning in Electronics" which was refused publication ~~f~~ or fobbed off in some other way a number of years ago by the IEE and the IEEE. The correspondence will give the details. This current writing follows that earlier material.

If energy current is flowing from A ~~to~~ B, it ~~can~~ can only flow; it cannot be pushed, because energy

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